High-radiance LDP source for mask-inspection application

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October 8, 2013

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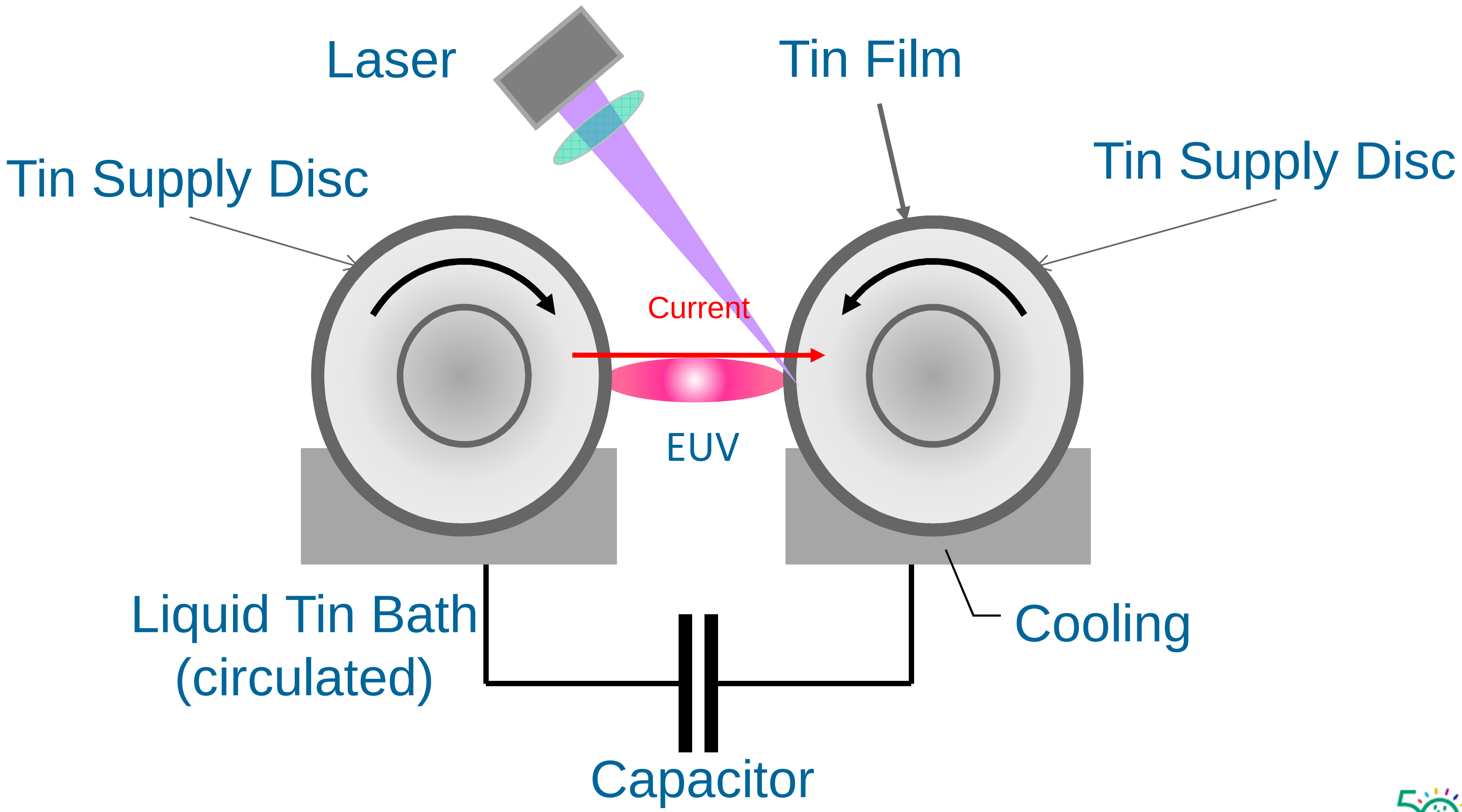
I N D E X

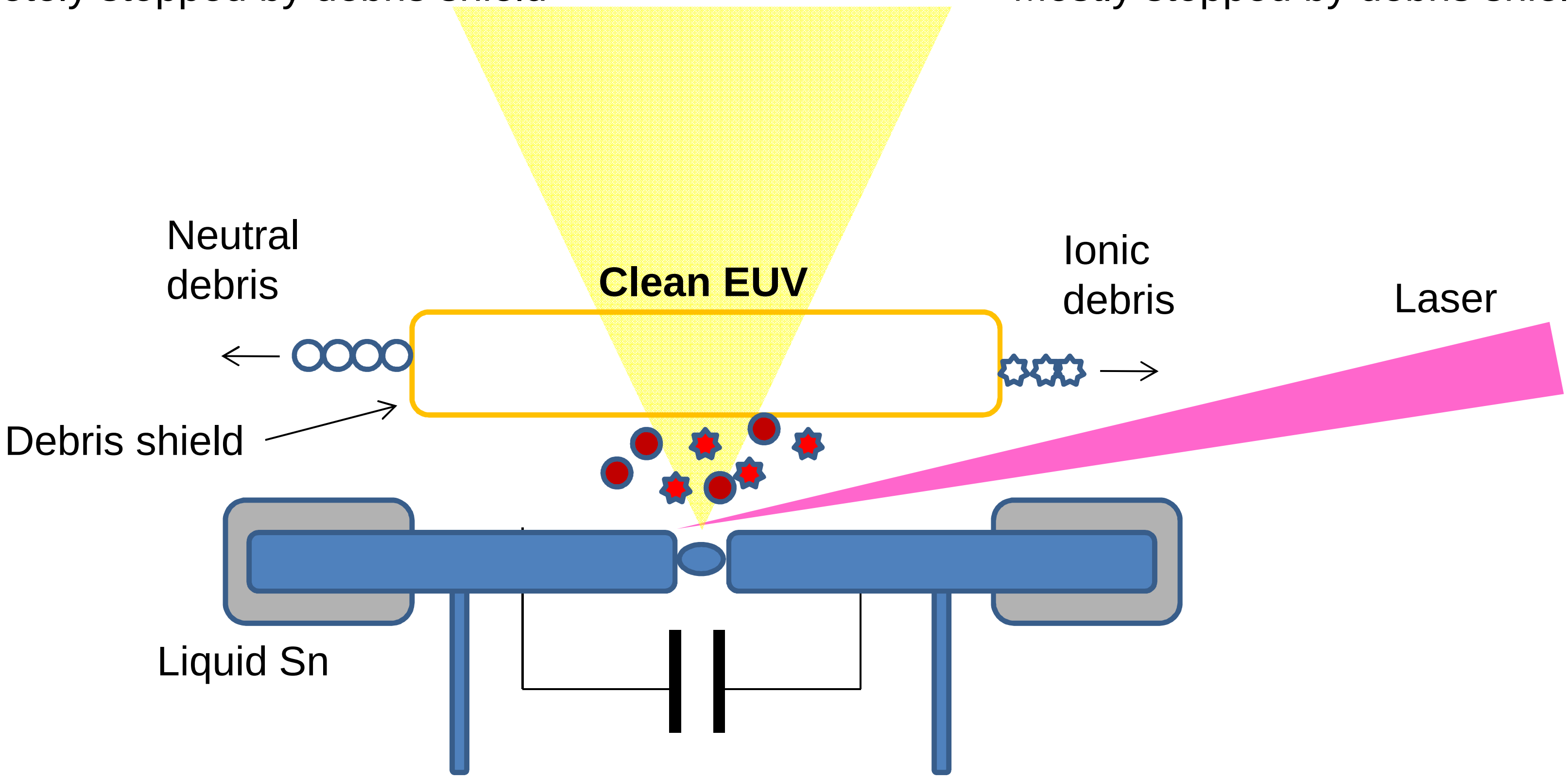
Sn + Laser + Discharge: Key for high radiance



LDP: High-radiance, clean, stable EUV photon to the tool

Neutral debris
(Macro/microscopic particles, gaseous debris)
- Completely stopped by debris shield

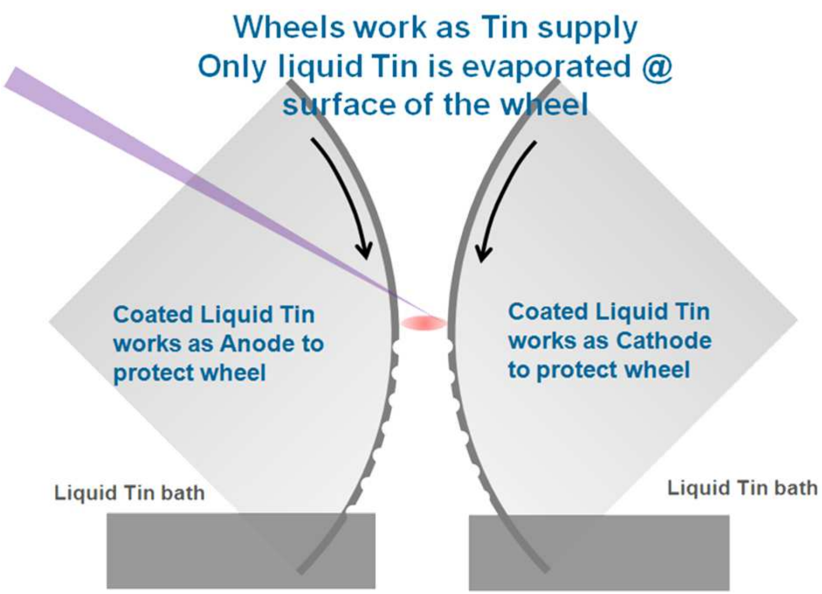
Ionic debris
(Charged particles)
- Mostly stopped by debris shield



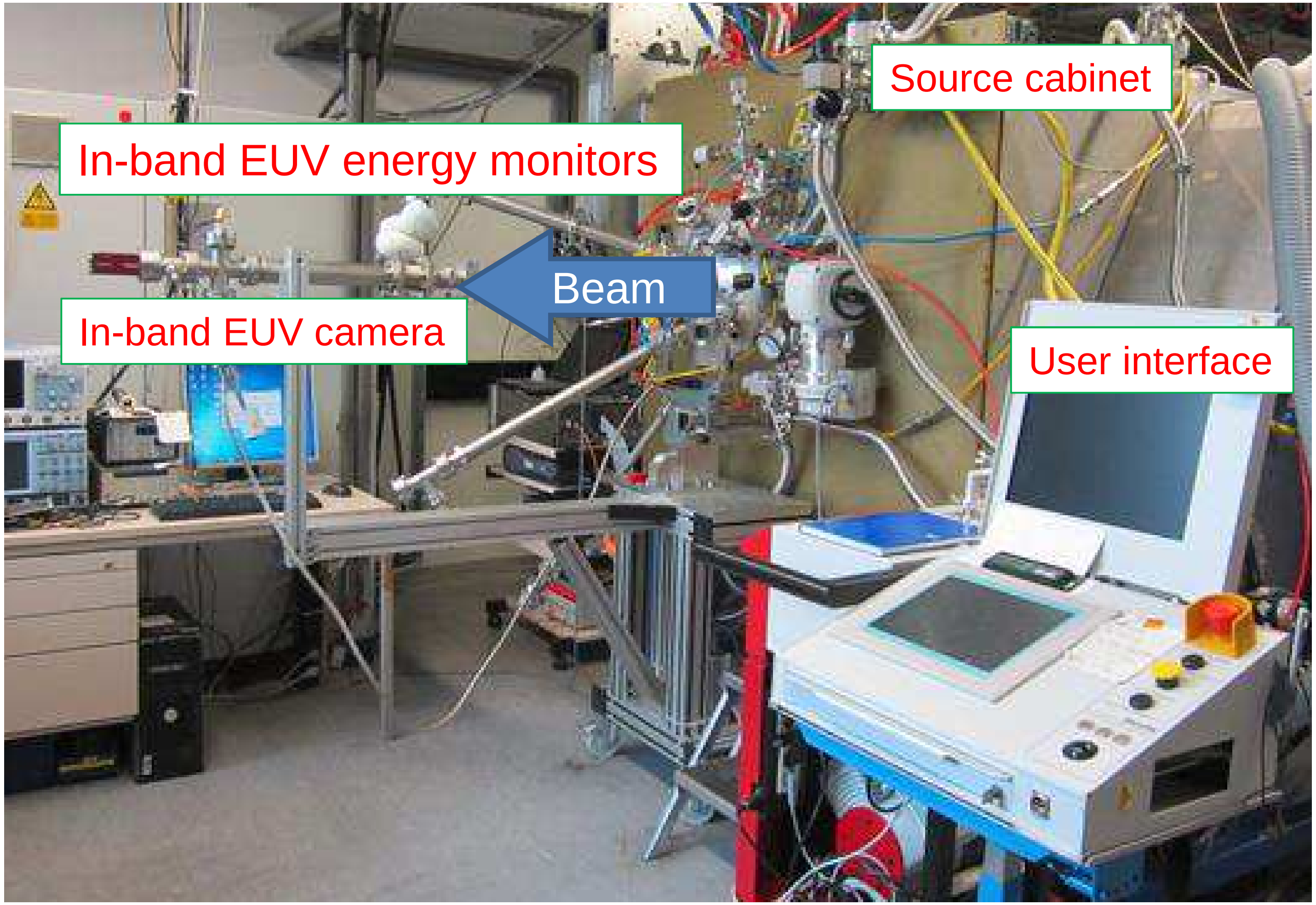
LDP: Stable and reliable

- **Tin is always available at all time (thin film) – No time discretization**
  - No timing error that would cause a loss of synchronization with the discharge

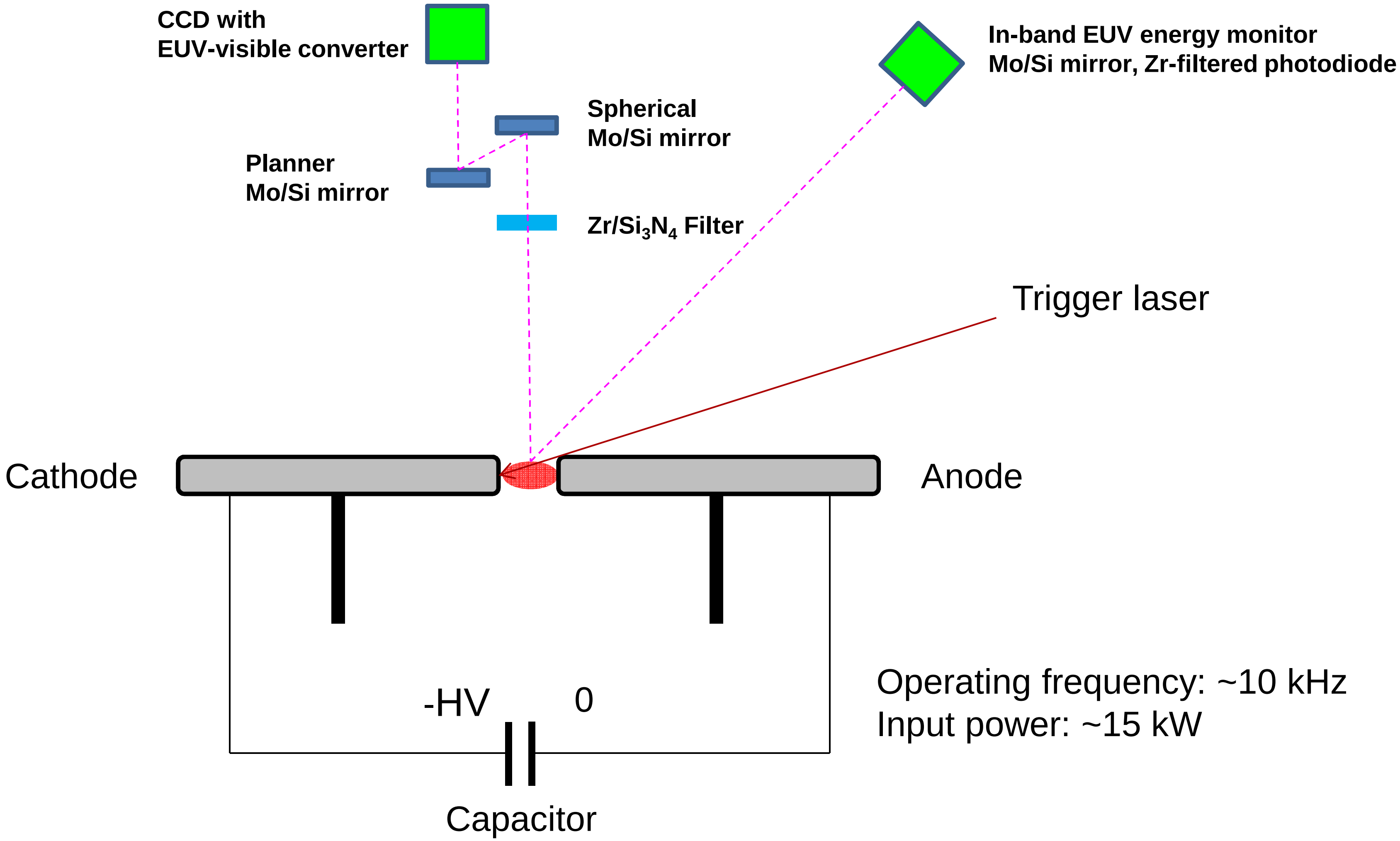
- **Tin is always at the same location – No spatial discretization**
  - No positional error that would result in instability in the conversion efficiency



Experimental system: PoC and debris-shield verification



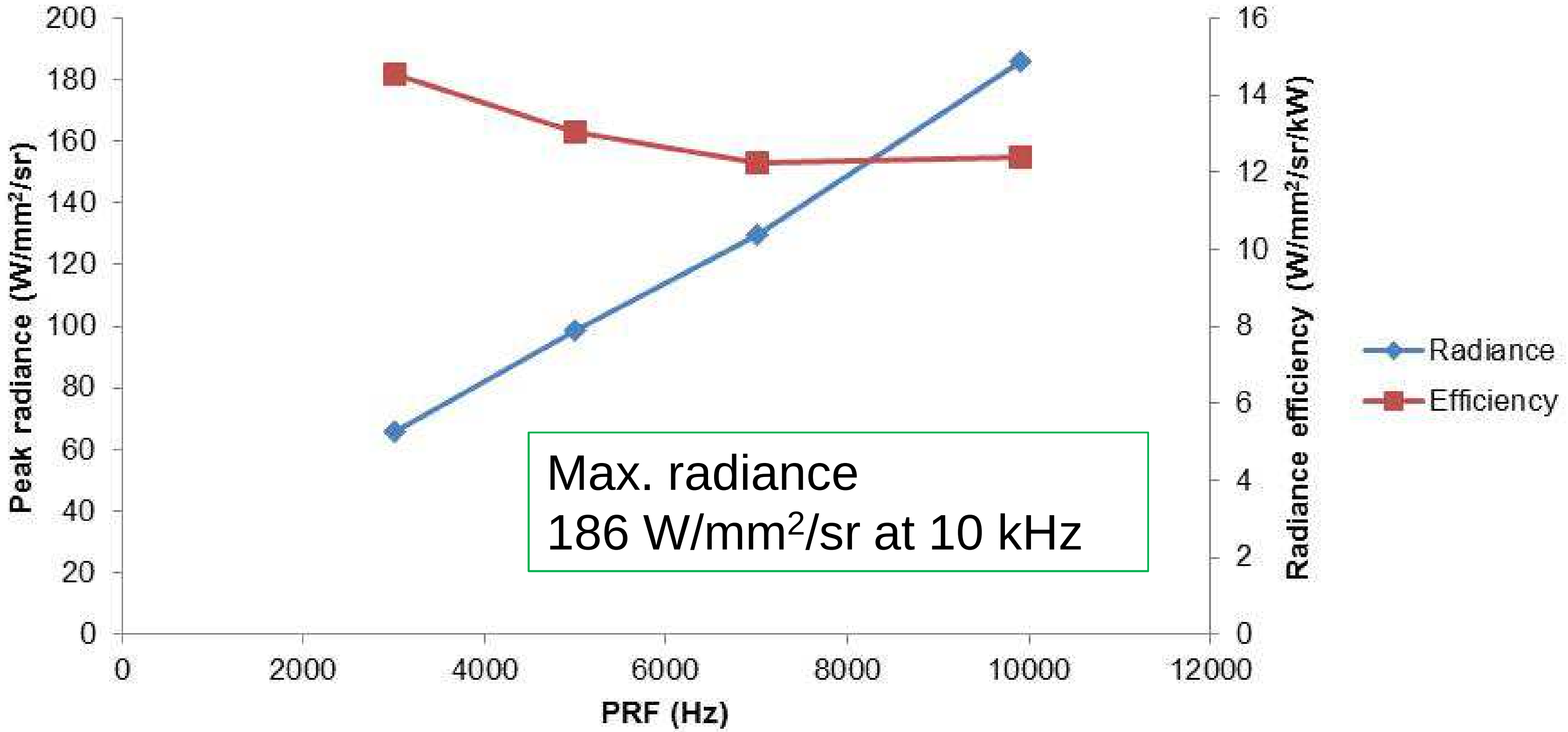
Radiance measurement



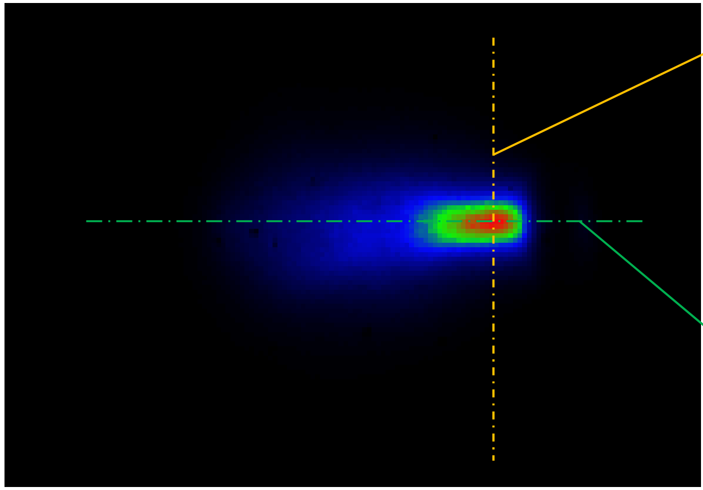
Operating frequency: ~10 kHz
Input power: ~15 kW

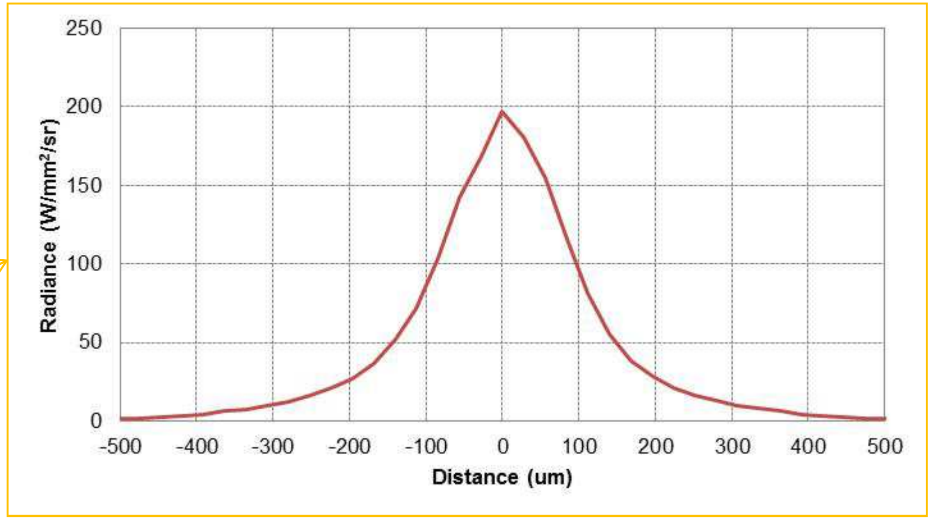
Pulse Repetition Frequency (PRF) scaling up to 10 kHz

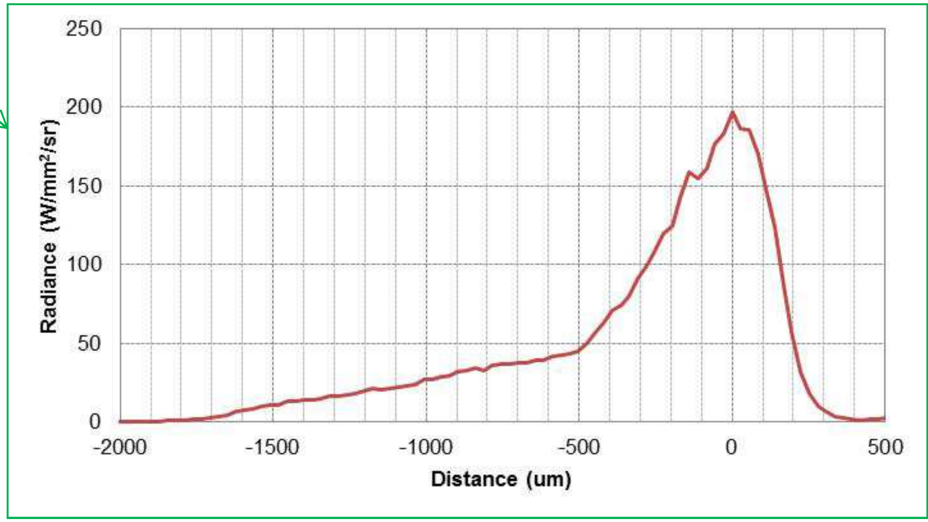
- Measurement was done up to 15 kW, 10 kHz.
- Radiance linearity has been confirmed with relatively higher efficiency at low frequency region.
- High efficiency (>12 $W/mm^2/sr/kW$) was maintained at 10 kHz. (ref. ~1 $W/mm^2/sr/kW$ in case of Xe GDPP)



Emission image and profile 10 kHz

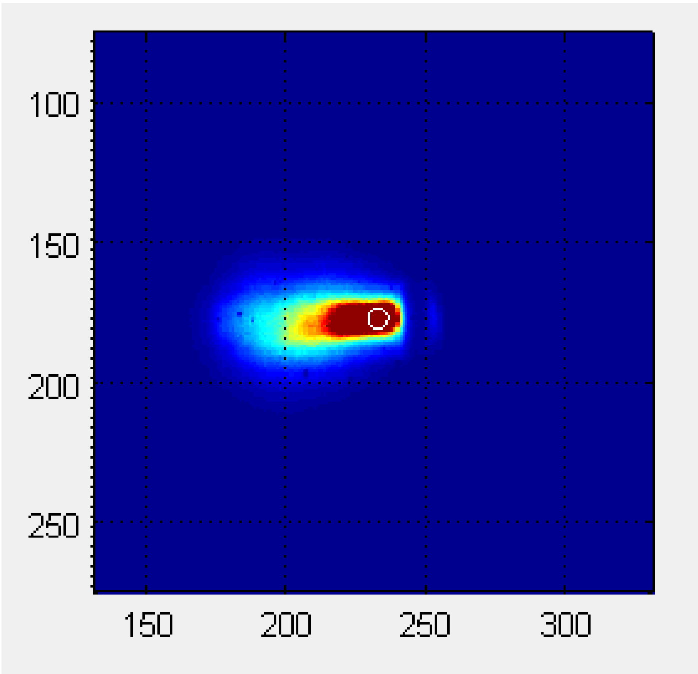


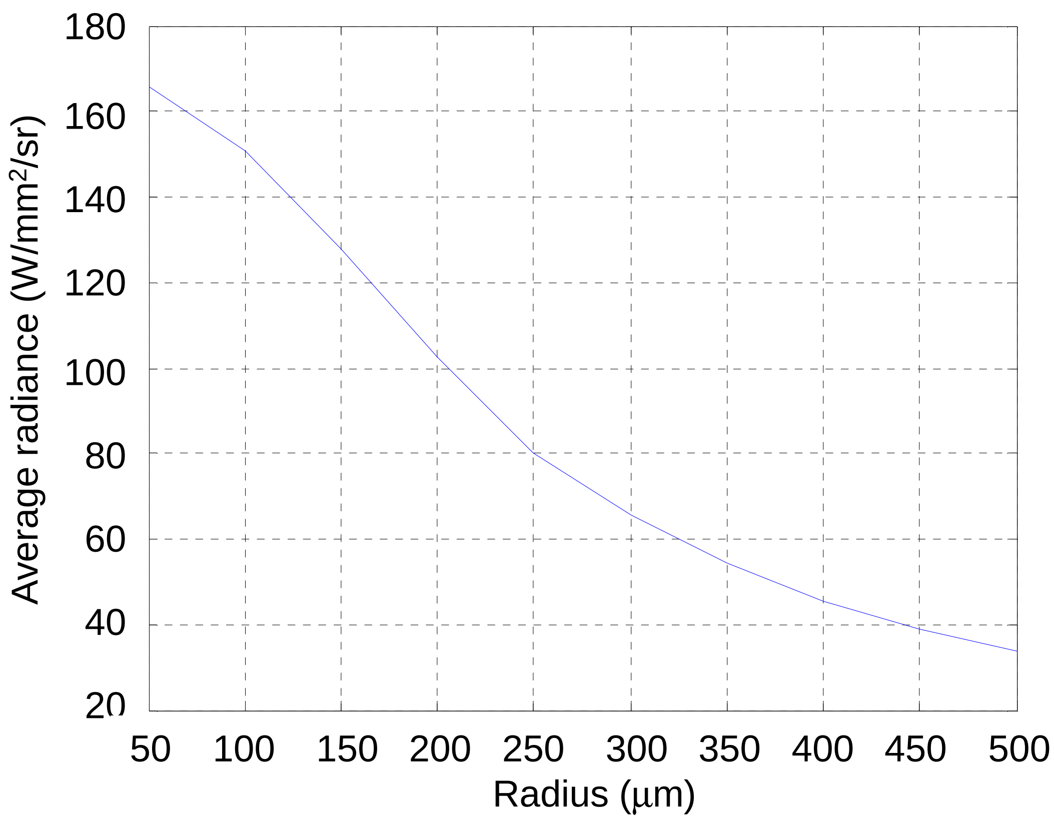




- ❑ Diameter: 200 μm (FWHM)
- ❑ Length: 450 μm (FWHM)

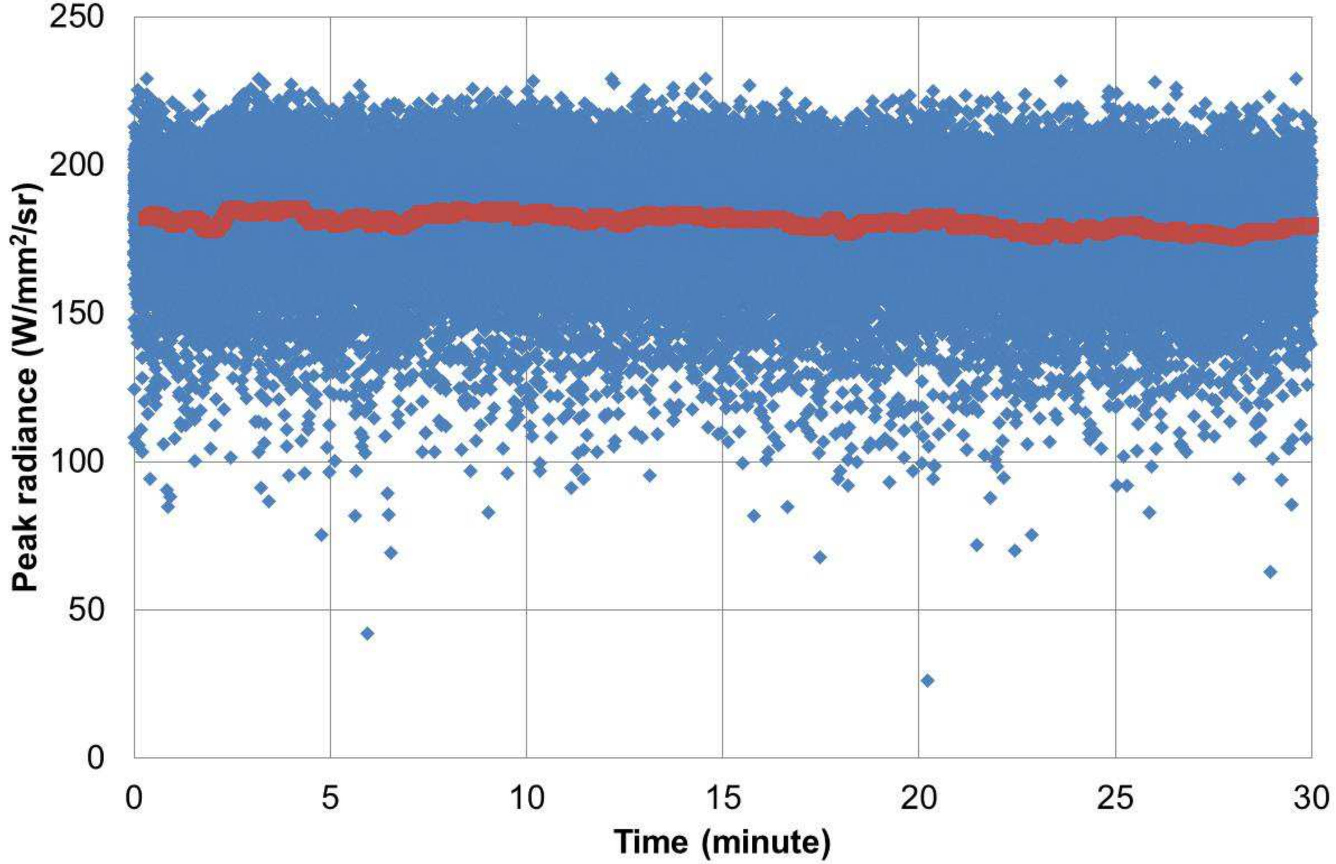
Averaged radiance vs plasma radius



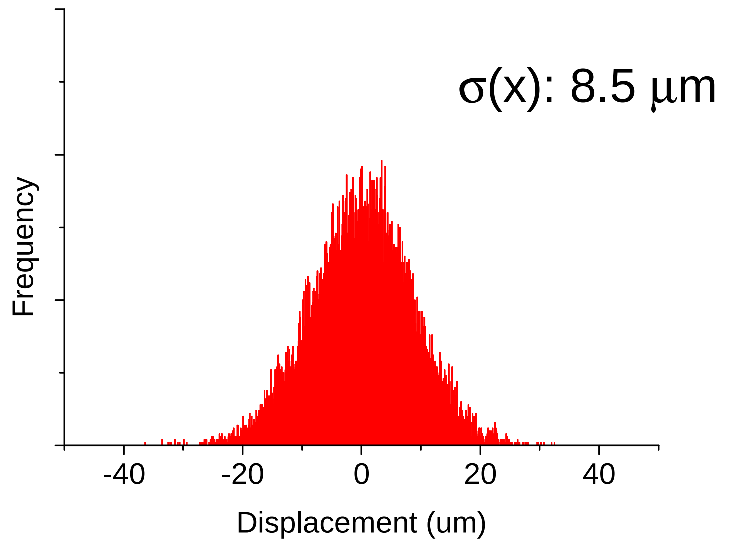


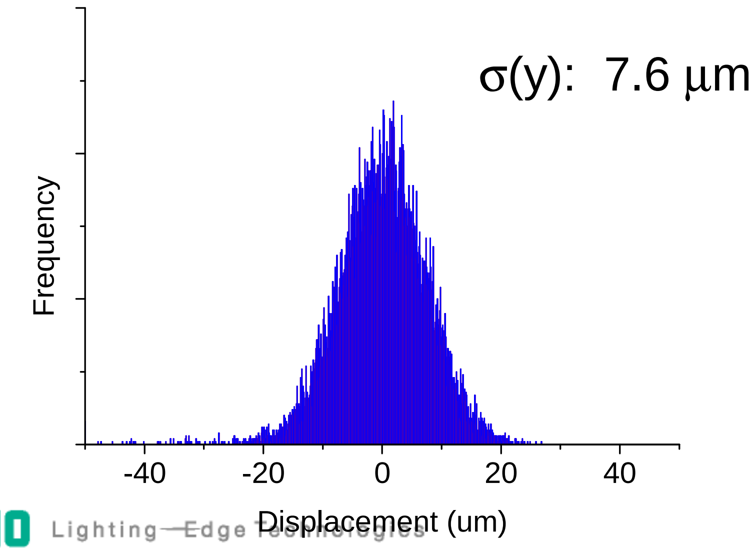
Radiance stability at 10 kHz

10 kHz (15 kW)
Dose-control off
Duty cycle 100 %
Frame-to-frame deviation: 9.7 %
300-frame-average deviation: 1.4 %



Position stability at 10 kHz

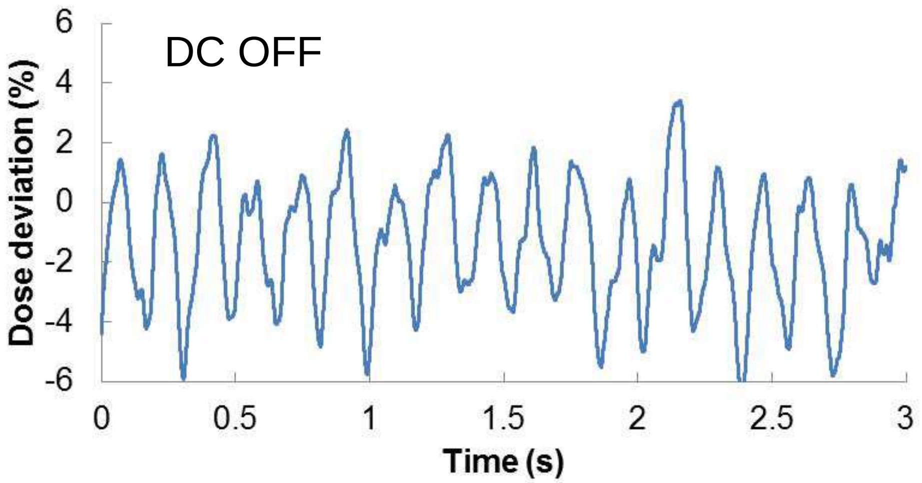




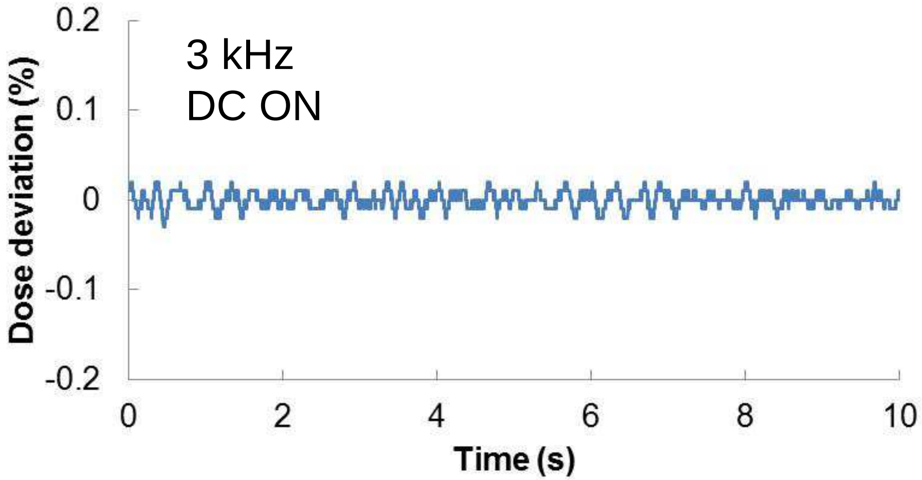
- ❑ Fluid dynamics
- ❑ Geometry
- ❑ Thermal stabilization

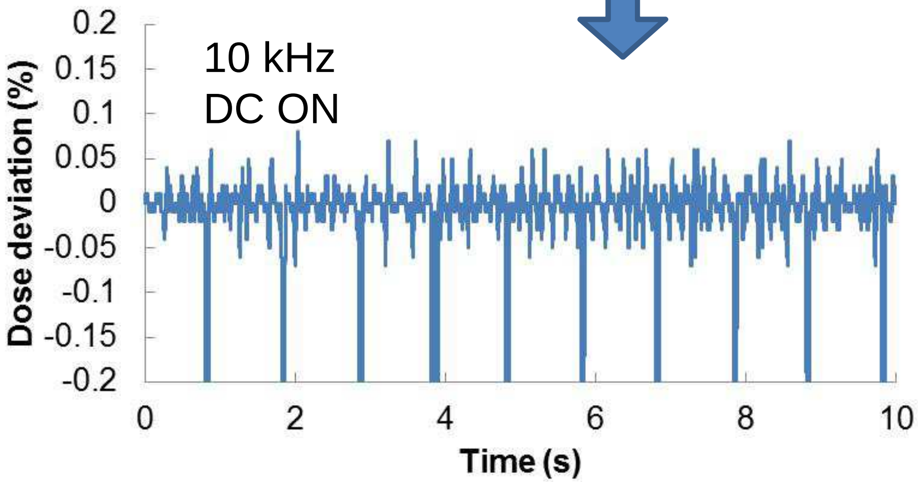
Energy/position stability improvement

Dose control test at 10 kHz



Periodic spikes will be eliminated by tuning dose-control software.



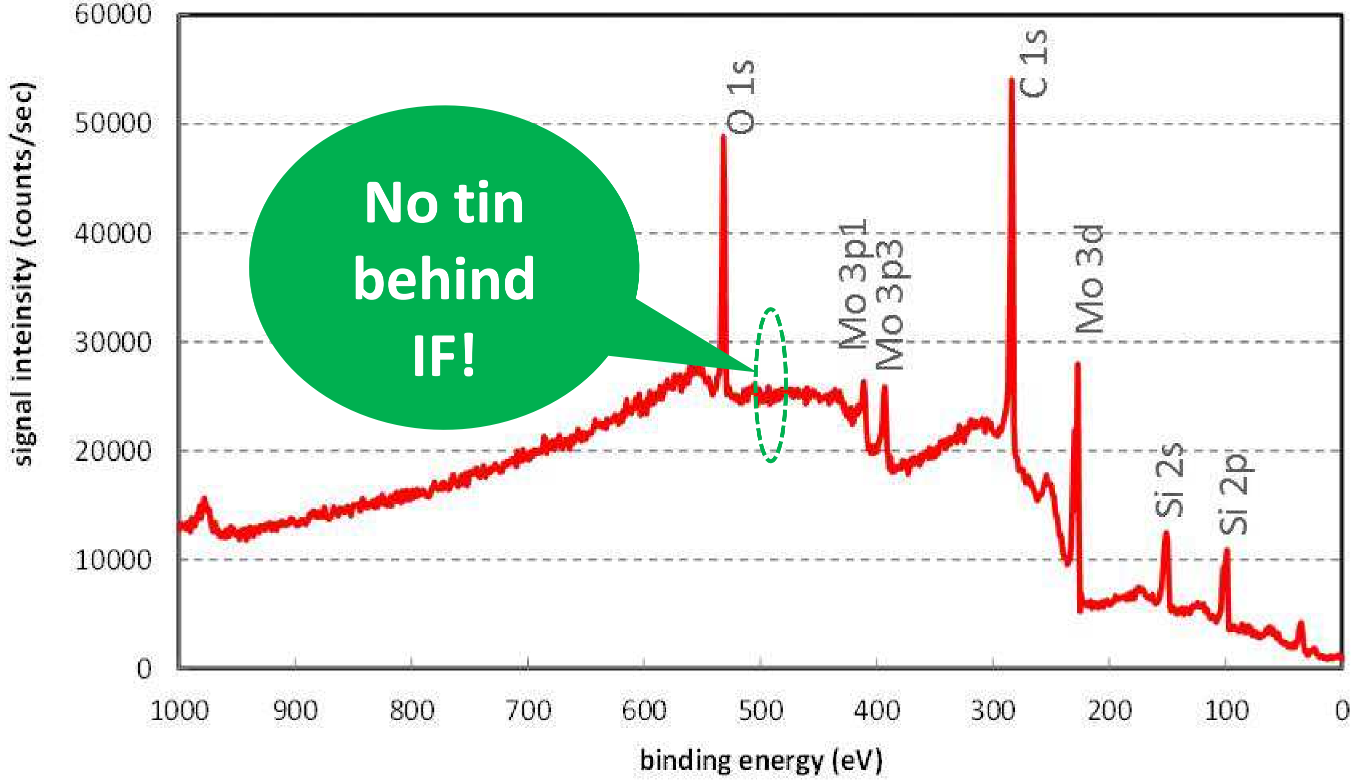


Dose control test at 10 kHz

Pulse repetition frequency		5 kHz	7 kHz	10 kHz DC OFF	10 kHz DC ON
E0	Stored energy	1.5 J	1.5 J	1.5 J	1.5 J
Average input	On capacitor	7.5 kW	10.5 kW	15 kW	15.2 kW
Peak radiance	At plasma	93 $W/mm^2/sr$	120 $W/mm^2/sr$	180 $W/mm^2/sr$	180 $W/mm^2/sr$
Energy	Pulse deviation	8.2 %	8.2 %	12.7 %	17.7 %
	Dose deviation	Not measured	Not measured	10%	<0.1 %
Radiance	Frame-to-frame deviation*	5.0 %	5.4 %	9.7 %	9.7 %
	Dose deviation**	0.7 %	0.7 %	1.4 %	0.7 %

* 1 frame = 1~2 ms exposure
** 300-frame moving average

Sample measurement after IF aperture in litho source



Conditions
Source input: 9 kW
Distance from IF: 200 mm
Exposure time: 6 hours
Estimated EUV intensity: 0.19 W/cm^2

✓ No tin peak (485-487 eV)

- Tin is completely blocked in LDP source
  - Analysis depth → 3-5 nm
  - Resolution → 0.1 At%

Summary

- Peak radiance at reasonable input power (15 kW, 10 kHz), under which sufficient component lifetime is obtainable, is 180~200 W/mm^2/sr at plasma (90~100 W/mm^2/sr after debris shield).

Performance summary (as of September 2013)

Item	Current performance	Remark
Pulse repetition frequency	10 kHz	Variable
Input power	15 kW	at capacitor
In-band EUV power	300 W/2πsr	at plasma
Peak radiance efficiency	12 W/mm^2/sr/kW	at plasma
Peak radiance	180 W/mm^2/sr	at plasma
Average radiance (ϕ200 mm)	150 W/mm^2/sr	at plasma
Plasma size	200×450 μm	FWHM
Energy stability	12.7 % (pulse) 10 % (300-pulse dose)	at 10 kHz DC OFF
	17.7 % (pulse) 0.1 % (300-pulse dose)	at 10 kHz DC ON
Peak radiance stability	9.7 % (frame) 1.4 % (300 frame)	at 10 kHz DC OFF
	9.7 % (frame) 0.7 % (300 frame)	at 10 kHz DC ON
Position stability	~10 μm	at 10 kHz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